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Existing Frameworks and Special Considerations

Risk assessment has been used and methods developed over what now amounts to decades of practice in the fields of environmental health, occupational health, and engineering. The framework, structure, and policy-making for such assessments have been extensively examined, notably in a series of reports published by the National Research Council (NRC). The seminal report, *Risk Assessment in the Federal Government: Managing the Process*, widely known as the "Red Book" (NRC 1983), brought structure to the risk-assessment process and defined its key components in a framework that has been nearly universally accepted ever since. Key methodological issues were considered in *Issues in Risk Assessment* (NRC 1993a); the role of uncertainty and its analysis was further explored in *Science and Judgment in Risk Assessment* (NRC 1994); use of risk information by decision-makers and the public was considered in *Understanding Risk: Informed Decisions in a Democratic Society* (NRC 1996); and a series of reports from the Committee on the Biological Effects of Ionizing Radiation (the BEIR Reports) (NRC 1972, 1974, 1980, 1988, 1990, 1999d) has treated methodological issues for radiation risk. Regulatory agencies have promulgated guidelines and procedures for their conduct and application of risk assessment, notably the Environmental Protection Agency's (EPA's) guidelines and its more recent revision proposals (EPA 1996). These broad-level statements are supplemented by a myriad of documents detailing policies, procedures, and guidance for various specific applications. Variation in methodology among federal agencies and an analysis of how methods are influenced by regulatory mandates have been reviewed (Rhomberg 1997). Many more reports and treatises could be cited.

In short, the questions of how to frame such inquiries, how to approach risk-assessment tasks, how to handle problematic issues, and how to bring the results to bear on the motivating policy issues are well explored. This is not to say that all questions are answered—if they were, the ongoing flow of advisory reports would cease—but the issues that remain do so because of their inherent difficulty, rather than any lack of attention.

This chapter examines current general frameworks for assessing risk and their utility for developing a framework for assessing risks to deployed U.S. forces. In addition, special aspects that are relevant to risk assessment for deployed troops are discussed.

EXISTING FRAMEWORKS FOR RISK ASSESSMENT

NRC's Red Book Paradigm

Overview

NRC (1983) provides a structure for conducting risk analysis that has served as the basis of virtually all discussion of the topic since it was proposed 16 years ago. Although this structure is familiar, it is so central to this task that it is worthwhile to recapitulate the main findings.

The NRC report advocated maintaining a distinction between risk assessment and risk management. Risk assessment was defined as the attempt to come to an objective characterization of the risks entailed by the process or agent in question among the population of interest. Risk management was defined as the process of using this information, along with information on the costs, feasibility, and effectiveness of various control measures and consideration of the interests and preferences, rights, and obligations of the parties involved, to arrive at decisions about what course of action to take regarding the existence of the risks. The aim of drawing the distinction is to allow a legitimate place for economic and social values, the balancing of conflicting interests, and other extra-scientific considerations to enter the decision-making process, while avoiding the contamination of the characterization of risks by these considerations.

This prescription is frequently misread to suggest that risk assessment must consider only "best" or "central" estimates of uncertain risks and that risk assessment and risk management must be entirely separate exercises carried out by different analysts. In fact, too rigid a separation only serves to hamper communication of the risk information to the risk-management decision-makers, who are best served when they are informed about what is known, what is not known, what is likely, and what is less likely yet possible about uncertain risks. Some decisions might be

sensitive to uncertainty in the risk estimates and others might not be; in some decisions, risk aversion has a role whereas others might require risk neutrality. In other words, risk assessment must be conducted so as to summarize what is known in an objective way, and to provide answers to the questions asked by the risk management process. These questions are quite legitimately value-laden, but the answers should aim at objectivity.

The technical and objective aspects of risk assessment must supply risk management with information that is technical, rational, and objective. In fact, the analysis of costs and effectiveness of alternative risk control or mitigation options is highly technical. Moreover, a large body of quantitative analytical methodology, usually referred to under the rubrics of operations research and decision science, can be brought to bear to find optimal solutions to allocating resources, by balancing risks against one another and against costs of mitigation, and to improve the design of procedures and actions that must be taken in the face of risk and uncertainty. These methods take as their inputs the characterization of risk provided by risk assessment and the characterization of the relative desirability of different outcomes, willingness to bear risks for certain ends, and willingness to expend resources to lower risks—factors that together comprise the values referred to above.

The full exploration of the analytical framework for risk management is beyond the scope of this report. But the spirit of this report's recommendation that the risk assessment framework be constructed to serve the ends of risk management requires careful attention to the kinds of analysis that risk information is intended to illuminate.

Returning to the Red Book's framework for risk analysis, the NRC (1983) proposed dividing the risk assessment-phase into four key components:

- Hazard identification—the assessment of the qualitative properties of an agent's toxicity, including an assessment of the weight of evidence that it might in principle be able to produce toxic effects in the population of interest, provided doses are sufficient.
- Dose-response analysis—the assessment of the quantitative relations between different degrees of exposure and the probability, magnitude, or severity of response to be expected among individuals in the target population.
- Exposure assessment—the estimation of the magnitudes of exposure or dose actually or potentially experienced by members of the target population in the situations of interest, including information on the variation in magnitude of this exposure in different circumstances.
- Risk characterization—in which the results of the other three components are brought together to provide estimates of the potential

impacts on the exposed population. Risk characterization also reviews the basis of the estimation and examines the contribution of uncertainties in the constituent elements on the uncertainty in the estimates.

The last step, risk characterization, is the point at which the analysis is condensed to the basic key findings that are likely to be most relevant to the risk-management process. It forms the interface between the two realms and can be thought of as belonging in part to each. The key for the risk assessor is to express findings that are most useful in risk-management decision-making. For risk managers, the key is to frame questions in a manner that best allows the technical analysis to bear on them.

Application of the Paradigm to Deployed Forces

Given the prominent role of the NRC (1983) paradigm in structuring risk analysis, how should it enter the present attempt to create a framework for the protection of deployed U.S. forces? First, although the paradigm was developed to assess toxic effects from environmental or occupational exposure to chemical agents, it is readily adaptable to analysis of a variety of hazards. This makes it appropriate to the protection of deployed forces, which face a variety of threats that must be considered in a common framework.

Hazard identification, for instance, can comprise any analysis of the qualitative properties of a threat to deployed forces. Although the specific means of inference will differ, the central concept of hazard identification applies equally well whether the threat is the possible carcinogenicity of an industrial chemical, possible mechanical failure of a complex piece of machinery, possible disease caused by a poorly understood infectious microbe indigenous to a remote deployment site, possible use of a certain military tactic by an adversary, or the impacts of physical or psychological stress on the troops' morale and fighting effectiveness. The common conceptual elements of hazard identification include (1) determination of the nature of impacts to be sought; (2) determination of the hazard's potential mode or modes of action; (3) description of losses or adverse outcomes that might be caused by the hazard; and (4) assessment of the basis for the present understanding of these properties (based on past experience, analogy with similar threats, experiments, or expert judgment) and our confidence that the properties so discerned apply to the particular setting. The result of this analysis is an assessment of the likelihood that specific adverse outcomes will be caused by specified conditions of exposure.

Similarly, the concept of exposure assessment can be applied to the

attempt to measure or estimate any quantities that express the varying degree or intensity of encounter with the source of threat, whether it is the uptake of a chemical from the environment, number of duty cycles for a machine, or concentrations of microbes in drinking water. The aim of exposure assessment is to examine the specific instances in which the undesirable outcomes are risked. This is achieved by defining and measuring quantities that describe the setting-specific magnitude of encounter with the threat in such a way that the probabilities of manifestation of the adverse outcomes are functions of the exposure magnitude. That is, the dose measurement is the independent variable, and the dose-response function is the expression of how the probability or magnitude of response is thought to vary as a function of the dose (Rhomberg 1995).

The NRC (1983) four-step paradigm for risk assessment allows a diversity of threats to be examined in a common context. It is recommended that even those types of hazards that are not usually explicitly analyzed using this paradigm be so analyzed by using it in the framework for assessment of risks to deployed forces. For example, risks of combat casualties, traffic accidents, aircraft malfunctions, industrial accidents, terrorist attacks, disease outbreaks, and adverse weather conditions could all be analyzed under a paradigm of similar conceptual structure. This would facilitate integration of the results of hazard-specific assessments and tracking of the complex process of simultaneous consideration of multiple threats, a critical part of organizing relevant information and developing risk management strategies, including trade-offs.

The NRC (1983) paradigm, however, is not sufficient by itself as a risk-assessment framework for protecting deployed U.S. forces. Although the paradigm can be applied to a variety of threats, it is constructed on the premise that one has already identified the specific hazards to be assessed and the settings in which exposure is expected to occur. That is, the NRC (1983) paradigm is a strategy for exploration, analysis, and characterization of particular threat scenarios that have previously been recognized and defined. It does not deal with the process of recognizing which particular actions and practices in a complex process (such as troop deployment) might require analysis of specific threats. It provides for no systematic way to catalog such threats, to set priorities for them, or to prepare a characterization of how the spectrum of hazards might change between deployments or locations, or as a particular deployment continues. It focuses on characterizing specified exposure scenarios rather than discovering modes of exposure or assessing the likelihood of circumstances that might lead to encounters with hazards.

In short, the standard structure of the NRC (1983) paradigm is a key part of the needed structure, but it should be nested inside the larger context of a comprehensive analysis of and response to the spectrum of

potential impacts on the health and safety of deployed troops and on mission success. To a large measure, the framework proposed herein is constructed to address these needs for an overarching structure.

A full risk-assessment framework for deployed forces needs to address these issues as a way of identifying hazardous situations and resulting exposure scenarios, which can then be examined and more fully characterized in the context of the traditional NRC (1983) paradigm. Moreover, the framework needs to provide for integration of the results of such analyses into a larger risk-management process in a way that tracks the completeness of the analysis and facilitates bringing the results to bear on achievement of the program's objectives. A framework proposed by the Presidential/Congressional Commission on Risk Assessment and Risk Management (PCCRARM 1997a,b) aims at considering this larger structure. It calls for embedding the risk analysis steps inside of a risk management decision-making context. The process is described as having six steps.

The first step is to characterize the risk management problem, including the goals of the process, the nature of the relevant data, the decision-making structures that will be applied, the roles of stakeholders, and the means of involving them. The second step is the risk analysis per se, conducted using appropriate methods while keeping in mind the questions the process is aimed at answering. The third step is the analysis of options to control or ameliorate the risks, with consideration of how actions on one risk will affect others and the costs and benefits of various actions. By explicitly placing the analysis of options in the framework, the ability of the risk analysis to make the distinctions necessary for choosing among options is highlighted. The fourth step is to make decisions based on the information on risks, goals, and expected consequences of various options, as determined by previous analysis. The basis of the decision should follow from the criteria set up at the outset. The fifth step is to take the risk management actions decided upon, and the sixth is to evaluate the effectiveness of those decisions, checking to see if the intended results indeed occur, and feeding the experience into improvement of the process in further iterations of the cycle.

This is a structure for both risk assessment and risk management, and, thus, it goes beyond the strict scope of what is being attempted by the present framework, which focuses on the characterization of risks. The Presidential/Congressional Commission's design has an important lesson, however: the risk assessment process must bear in mind the questions being asked of it by the larger risk management, decision-making process in order to identify the distinctions that need to be made in choosing courses of action, the ways in which risk assessment results should be expressed so as to be useful in making decisions, and the way in which risks interact with one another and with the costs of addressing them.

Another important lesson is that stated goals are necessary, and the success of the process at achieving those goals should be subject to ongoing evaluation. The framework developed in the present report attempts to embody the spirit of the Commission's approach. While it does not take on the full problem of risk management for deployed forces, it does attempt to examine some of the aspects of that management that are particular to the context of deployed forces health protection and the consequent demands that this puts on the risk assessment process.

Another existing framework to consider is the one applied in environmental public health surveillance (Weeks 1991; NCEH 1996; Thacker et al. 1996). The primary issue here is to achieve public health protection by detecting the existence of threats as they are happening through programs of surveillance. Once detected, further evaluation can determine causal pathways and opportunities for prevention and intervention. Depending on the nature of the threats, it might be more efficient to conduct surveillance for hazards, for exposures, or for outcomes. Tracking outcomes in the population of interest has the advantage of detecting the impacts and might be appropriate when causes are unclear or when effects can result from multiple causes, but the disadvantage is that adverse impacts must happen in order to be detected. If causes cannot be established, opportunities for prevention might be circumscribed. Once particular exposures are recognized as potentially harmful, conducting surveillance for instances of such exposure provides the opportunity for intervention before undue harm is caused. Surveillance for hazards, if possible, is preferred in that it gives the earliest opportunity to intervene, preventing exposures before they begin.

This public health surveillance approach is applicable to the situation of troop deployments. In the framework developed herein, outcomes surveillance largely correspond to the recommendations for health surveillance during and after deployments. Companion reports examine health surveillance issues (IOM 1999) and exposure surveillance (NRC 1999a). To a large degree, the emphasis of the framework suggested in the present report is an attempt to embody the aims of hazard surveillance, and the lesson learned from the public health paradigm is the need to seek out unrecognized potential sources of harmful exposure.

The Kaplan-Garrick Definition of Risk

Overview

Another seminal publication that addresses the structure of risk analysis and contributes to the approach suggested here is the first paper to be published in the journal *Risk Analysis*, a treatise on the definition of risk

by Kaplan and Garrick (1981). Risks in their definition are sets of triples, each formed by (1) a scenario (i.e., a hypothetical future event or set of events), (2) the likelihood of the scenario occurring, and (3) the consequences of the scenario. A risk question can be expressed as a mutually exclusive set of such triples, with each set determined by selecting alternative courses of events, and each set having its own probability of transpiring and probable outcome.

This definition calls attention to some important facts about risks. For one thing, risk is about uncertainty and indeterminacy. In doing risk analysis, there is no need to be sure in the prediction of outcomes, only a need to express a belief regarding the likelihood of the different possible outcomes. The point of the risk analysis is to characterize the probabilities as a guide to what actions should be taken now in the face of an uncertain future course of events.

There is sometimes confusion about this aspect, particularly in risk assessment of environmental contaminants, because the problem is cast as one of predicting what will happen to the health of people who happen to receive a certain dose of the agent. When, owing to lack of information or incomplete understanding of the underlying biology, this prediction is subject to great uncertainty, it is sometimes said that one "cannot do risk assessment" because the risks are too uncertain. In fact, this confuses two aspects of risk analysis. One aspect is the attempt by the analyst to use information and scientific understanding to narrow, insofar as possible, the uncertainties about the consequences of exposure and the probabilities of the consequences occurring. It is ironic that, to the extent that the analysis succeeds in being able to make such predictions with certainty, it ceases to become a risk analysis in the strict sense because there is no longer uncertainty about any adverse outcomes. The second aspect of risk assessment is to acknowledge and characterize the uncertainty that remains, and to communicate that characterization as input in an analysis of what should be done in the face of that uncertainty.

Even when predictions can be improved, they rarely can predict which particular individuals in an exposed population will succumb to an adverse health event. At the level of the exposed population, one might be fairly confident in predicting, for example, the approximate fraction of people who will become ill after ingesting water contaminated with an infectious microbe, but for each exposed individual the risk is whether or not he will be among that fraction.

This illustrates that, in characterizing a risk, the way in which the possible courses of events are divided into distinct scenarios depends on the question being asked. In the example just mentioned, a population-level analysis might define the set of scenarios as "no one in the unit becomes ill," "a few troops in the unit become ill," or "a substantial

fraction of the unit becomes ill." At the individual level, the scenarios might be "I do not become ill," "I become slightly ill," or "I become seriously ill."

The Kaplan-Garrick definition of risk also points out that the probabilities involved are Bayesian probabilities, in that they are best guesses about of the likelihood of the alternative courses of events. As further information is gained, these probabilities can be updated to reflect a more thorough understanding. The uncertainty arises both because outcomes are contingent on the unknown course of future events and because of the limits to understanding the causal processes involved.

Application of the Definition to Deployed Forces

The scope of the risk analysis dictates how the alternative scenarios are defined. In practice, because there might be many possible unfoldings of events that are of interest, the set of scenarios can become very complex. Often, scenarios are not single events but rather compound sets of events, some of which might be more easily analyzed as separate components of the overall risk. For example, in analyzing the potential benefit of providing protective garments to troops deployed in a region where terrorists might sabotage chemical storage facilities, the threat to the troops' health (the outcome of interest) occurs as a result of a complex scenario. For analysis, one might divide the compound event into a series of components, perhaps including the likelihood that troops will be stationed near such a storage facility, the likelihood that it is indeed sabotaged, the likelihood that the released chemical plume is transported in the direction of the troops, the likelihood that warning devices will operate correctly, the likelihood that troops will nonetheless get a critical level of exposure, and the likelihood that individual soldiers will succumb. Very different kinds of data, modeling, and analytical approaches are needed to estimate each of the probabilities in this chain. The best route to estimating the likelihood of the whole scenario is to separately analyze the parts, allowing for the contingencies. Moreover, analyzing chains of events in this way permits greater insight into how probabilities of end consequences change in a real situation as the actual course of events unfolds. In addition, scenario analysis provides focus on the points where actions and equipment operation have their effects on risks, providing targets for risk management strategies. It also calls attention to junctures where different risks can interact. In the example just discussed, the protective garments may cause their own impacts on health and well-being or they might exacerbate reactions to other agents.

In general, components that are valuable to analyze are (1) the likelihood of the presence of a hazard associated with a deployment; (2) the

likelihood of releases of agents into the environment, given their presence; (3) the likelihood that troops will suffer exposure (of various magnitudes), given the releases; and (4) the likelihood that health effects will be caused among them, given the exposure. Clearly, the specific way in which complex scenarios are broken down will depend on the particular instance, but components like the ones just suggested might often be involved. The value of looking at whole scenarios is that it emphasizes that threats must be dealt with in context, not one by one, with attention to the ranges of exposure as well as the toxic properties of agents that might be encountered. It parses the problem into parts that can be addressed by different kinds of analyses, and identifies components that take different amounts of effort and data collection to address. Assessing how various activities and practices affect the safety and health of deployed forces should involve tracing the consequences of alternative deployment practices and activities through their effects on exposure and possible adverse outcomes, bearing in mind the likelihoods of the various components. For instance, in the chemical storage sabotage scenario discussed above, the benefits of protective garments can be analyzed in the context of the likelihood that their protection will come to be needed compared to the decrement in military performance and troops' well-being that their use might entail. The opportunity for interaction of prophylactic agents and procedures with other hazards can be noted and the need to understand such interactions pointed out.

This view of risk analysis is somewhat more expansive than is often taken, but it serves the purposes of a framework for assessing threats to deployed forces. A more traditional approach might begin by focusing on identified toxic agents, then assessing their potencies, identifying likely exposure scenarios and characterizing their consequences, and then investigating what changes in practice might avoid or mitigate the risks. What such an approach tends to lack is a focus on finding those aspects of the whole body of activities and practices that might entail some sort of hazard. In quantitative assessment of risks to deployed forces, the likelihood that exposure events will come to pass might be as, or more, important than the probability of adverse effects to a given exposure.

SPECIAL CONSIDERATIONS ABOUT RISK ASSESSMENT FOR DEPLOYMENT

It is worthwhile to ask what special considerations are required for a framework for risk analysis in the case of assessing threats to the health and safety of deployed troops. Some of the special challenges and needs surrounding risk analysis for deployed forces are discussed in Chapter 2. Here, we examine how the practice of risk analysis might need to be

adapted to meet those needs. Several technical matters suggest some alterations in conventional risk-assessment methodology and other issues that relate to the unique risk-management challenges presented by troop deployment—challenges that the framework for conducting analyses of threats to deployed forces should be designed to address. Because risk analysis is above all a practical discipline, aimed at addressing the questions at hand, it is well to review the special considerations for deployed-forces risk-assessments.

Need for a Comprehensive Catalog of Hazards

The military is in need of a comprehensive catalog of assessments of all of the hazards that actually impinge or might impinge on deployed troops, and not just a threat-by-threat analysis. Many troops might be exposed to many of the relevant threats simultaneously, and their protection entails addressing the whole array of threats. Any action taken to address one threat is likely to alter the risks from other threats. This means that the incremental, piecemeal approach that a regulatory agency might take in addressing the various hazards under its purview might not by itself be sufficient. This approach places a great premium on cataloging all of the potential threats and setting priorities for them for detailed attention, but it still requires a framework for operating on many fronts at once. The primary objective is the integrated analysis of the spectrum of threats that troops might experience. Moreover, the question "Threats to whom?" has diverse answers: one is interested in threats to the health of individual service personnel while deployed, in cumulative career-long and life-long risk profiles, and in threats to the capabilities of whole military units or to the success of missions.

DOD Is a Regulator and Is Regulated

DOD has roles akin to being both the "regulating" and the "regulated" parties in many of its risk-assessment activities in the sense that it must identify hazards and establish health-protection exposure criteria on the one hand and act to implement those criteria on the other. (It is also true that many risk-assessment activities fall under the authority of other governmental regulatory bodies.) Although some assessment is carried out as an internal risk-management process, the effectiveness of this process is subject to external criticism and expectations. In the world of environmental regulation, the division among regulators, the regulated community, and interest groups in a publicly debated give-and-take process plays a role in shaping approaches to health-protection measures and in ensuring scrutiny and review of results. This

interaction needs to be replaced by an alternative review process in the military setting.

The Military Mission Has Primacy

When considering acceptable risks, the needs of the military mission must receive primacy. Although the challenge of risk trade-offs is universal, it plays a particularly marked role in the military setting. With sufficient military justification, it might be necessary to accept more risk than would be possible in a civilian setting. Accommodations for safety have consequences on military effectiveness and risks to the mission, personnel, and materiel that might be immediate and potentially large. Although risks of immediate casualties have always played a large role in military planning, the attention paid to possible longer-term chronic effects with delayed impact is a newer and increasing concern. This entails explicit recognition of the necessary trade-offs that are made between military effectiveness, mobility, and preparedness, on the one hand, and risks of immediate casualties, longer-term loss of health and well-being of service personnel, potential future governmental liabilities for treatment and compensation of deployed veterans, and even effects on morale and the reputation of the military for protecting troops, on the other hand. The burdens produced by accommodation of health and safety concerns, comprising equipment, logistic impediments, and training, as well as time and attention, can affect the military significantly. One must also consider risks induced by prophylaxis and protective equipment in balance with the risks from hazards they are designed to combat.

Margins of Safety

Because of the foregoing, incorporating "margins of safety" or conservative estimates of acceptable exposures, as is frequently done in environmental and occupational health settings, is not always useful to the needs of military risk management. When a high level of health and safety protection can be achieved without undue burdens or increases in other risks, such margins can be part of an effective risk-management program. But when risks must be borne or when probabilities of casualties must be weighed against immediate military considerations, best estimates of probable impact are more useful. The proper use and interpretation of uncertainty factors is complex and a full discussion is beyond the scope of this report. Risk assessment best serves risk managers when there is a careful distinction among needed extrapolation adjustments, allowances for uncertainty, and out-and-out margins of safety. Whether

assessments for deployed troops need special values for the uncertainty factors is a question worthy of further consideration.

Utility to Field Commanders

During deployment, especially in high-intensity situations, consequential decisions affecting responses to or defense against potential hazards might often need to be made by field-level commanders with modest relevant technical expertise and little time to gather and analyze relevant data. In civilian environmental health decision-making, in which issues are usually less pressing, it is typically possible to more thoroughly analyze specific situations, accumulate and analyze data, and subject the questions to centralized expert analysis. In the military situation, however, there is a great premium on anticipatory analysis and contingency planning so that sufficient information and careful, expert analysis can be used to prepare insight into difficult situations before they occur. There is also a need for designing operational procedures for use during deployment that capture the key considerations of risk-management problems. These procedures would provide straightforward guides and tools for commanders, allowing them flexibility and freedom to make rapid yet appropriate decisions based on changing current situations without abandoning the larger health and safety considerations.

Intentionally Created Hazards

Environmental hazards might be insidious, but they do not arise from malice. In contrast, troops can be subject to intentionally created hazards through terrorism or sabotage, and these hazards can be aimed specifically at the troops' vulnerabilities.

Different Types of Risk

The specific nature of many of the threats to troops is different from threats that are encountered in the civilian risk-assessment setting. There are no well-established methods for assessing risks for some potential threats of particular importance to deployed troops, such as from infectious diseases or from psychological and physical stress.

Specialized Exposure Conditions

Many exposure factors are different for deployed troops, and the standard assumptions made for general population environmental protection or for industrial hygiene applications might need modification for

the military setting. Deployment durations (and hence, exposure durations) can be less than the career-long or lifelong assumptions usually made, but work days could be longer (up to continuous), inhalation rates and water consumption higher, opportunities for dermal contact increased, and modifications by climate might be important. Food and water sources can be controlled or at least partly controlled.

Multiple Exposures

Troops during deployment could become exposed to a number of threats simultaneously. Exposures that are individually tolerable without appreciable risk might not be so when several are experienced together, and the question of interactions among agents looms particularly large for deployment risk assessment.

The Population at Risk

The nature of the population at risk in the military setting is different from the civilian setting. Compared with the general population, troops are typically young and healthy (and perhaps more tolerant of threats), yet their exposure in settings of high physical or psychological stress might raise susceptibility. As a group, they are as racially and ethnically diverse as the general population, so susceptibility variation due to genetic differences is not reduced, but it might be possible to develop and use information on individual genetic susceptibilities to limit exposures to those who suffer the most risk. Most troops are young when exposed; they will have more time than the general population for the effects of long latency to appear, and such effects will be less subject to diminution by competing risks. Young troops have most or all of their childbearing years ahead of them, and female troops face the possibility of deployment during critical but perhaps unrecognized early stages of pregnancy. Exposures during deployment, and any after-effects they might produce, can be potential factors in the health status of the troops through a long life. Whether these special features of the population at risk warrant alteration of traditional uncertainty factors or inclusion of special quantitative considerations is a question worthy of examination.

DOD's Control Over Population at Risk

The military has a considerable degree of control over the population at risk and its actions regarding that population. This gives opportunities to modify or control exposures in ways not available in a civilian setting, and it also requires that a degree of responsibility be taken for the appro-

priateness of actions and risks imposed on troops. The military has the potential to gather and utilize a good deal of information about locations of troops, their activities, their exposures, personal medical and exposure histories, genetic differences, and characterization of baseline rates of exposure—all information not readily available to civilian risk managers. There is the potential to make assignments based on past exposures or special sensitivities, avoiding exposures of those particularly susceptible to a hazard. The availability of this information and the ability to exert a good deal of control over the locations and activities of its personnel leads to opportunities and challenges. One can entertain an approach in which control of activities around sources of risk or tracking of cumulative exposures is used to ensure that individuals do not exceed a quota of risk. Although this approach is used for radiation workers, it is considered inappropriate for most civilian occupational settings. In contrast, civilian environmental regulators must assume that the population acts as free agents, so it is necessary to control sources of exposure rather than to control the actions of the public in encountering those sources.

DOD's Special Responsibility in Managing Risk

Because much of military activity entails higher risks than are typically found in general civilian life, because almost every command decision at all levels is to some degree a decision to expose someone to more or less of those risks, and because military personnel have, in the interests of organizational efficiency, discipline, and the common good, ceded some of their personal control over their lives and actions to this command structure, the military has a particular responsibility to manage risk-taking wisely and fairly. The military also has the need to call for individual sacrifice, acting to put its troops at hazard of life, limb, and health in the interests of the nation at large. This setting poses special challenges for risk management and for risk communication with the affected population. Articulating these responsibilities is beyond the scope of this report; it is not a risk assessment task per se, but it should affect the priorities and foci of DOD's risk assessment efforts. It is part of the process of using risk analysis to fulfill the public's expectations about the military's stewardship of the health and well-being of its personnel.

SUMMARY AND CONCLUSIONS

Previous examinations of the framework, structure, and policy-making for risk assessments provide useful information for developing a risk assessment framework for deployed U.S. forces. One of the most important and relevant outcomes of those efforts is to conduct risk as-

sessments so as to provide useful answers to the questions asked by risk managers.

The NRC (1983) paradigm for risk assessment has maintained a prominent role for structuring risk analyses in ways that are useful to risk managers, and the paradigm is readily adaptable to deployed-forces protection. However, it does not deal with the process of recognizing what particular actions and practices that are done in a complex process (such as troop deployment) might lead to threats that need to be analyzed. That need is fulfilled by incorporating the Kaplan and Garrick (1981) definition of risk into the NRC (1983) paradigm. From that basis, a risk-assessment framework can be developed with components to analyze: (1) the likelihood of the presence of a hazard associated with a deployment; (2) the likelihood of releases of agents into the environment, given their presence; (3) the likelihood that troops will suffer exposure (of various magnitudes), given the releases; and (4) the likelihood that health effects will be caused among them, given the exposure. Such a framework begins by examining *activities* rather than *specific agents*, as is done in more-traditional risk assessments. In that way, efforts would be focused on how activities and practices come to present threats, how likely it is that threats will be manifested in practice, and how mitigating one risk might raise other risks.

In addition to drawing upon existing risk-assessment frameworks, it is important to consider special needs and aspects of U.S. troop deployment. A useful framework in this context must be aware of DOD's need to accomplish inherently risky missions while also protecting its troops from a wide variety of hazards that can be caused unintentionally or intentionally. Also, the framework must be responsive to DOD's need to make risk trade-off decisions. Therefore, risk estimates must be realistic (not overly conservative) and readily useful to field commanders. In addition, the uncommon exposure conditions and types of hazards encountered during deployment, as well as troop population characteristics, warrant special consideration.